

NOTES ON THE EARLY-TYPE COMPONENTS OF W Cep, o Cet,

CH Cyg, AR Mon, and BL Tel

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ABSTRACT

Low-resolution IUE spectra in both spectral regions have been used to clarify the nature of the warmer components of several binary systems. W Cep, the primary of which is a luminous K-type supergiant, shows an ultraviolet absorption spectrum of type B0 or B1; this system is heavily reddened. The hot companion of Mira (o Cet) is surprisingly faint in the short-wavelength region, but it excites a rich emission spectrum from the surrounding gas. The ultraviolet-active M7 giant CH Cyg is shown to be a binary with a hot companion. This system has also been observed at high resolution and shows variable Fe II emission and well-separated circumstellar and interstellar absorptions within the broad Mg II emission profiles. The eclipsing binaries AR Mon and BL Tel are shown not to have hot companions.

INTRODUCTION

Ultraviolet spectroscopy can add an important dimension to the study of binary stars. In many cases, a hot secondary component whose presence can only be indirectly inferred from optical observations can be accurately classified in the ultraviolet. In other cases it may be important merely to be able to show that no hot component exists. Furthermore, the presence of strong transitions of many abundant ions makes the ultraviolet especially suitable for studying the interactions between components of a binary system, which may take the form of emission from a surrounding nebula or absorption from a circumstellar shell.

RESULTS

W Cephei

This semi-regular variable is a luminous K-type supergiant with a hot companion which fills in the spectrum shortward of about 4000 Å. The system has been classified K0ep Ia + O? (Bidelman 1954; Cowley 1969) and has been discussed with the VV Cephei stars (whose primaries are mostly of type M) by Cowley (1969). Since no lines are clearly seen in the near-ultraviolet spectrum of the companion, satellite observations in the far ultraviolet are needed to determine its spectral class.

Exposure times of 15 and 30 min were used to record the long- and short-wavelength regions, respectively, at low resolution. The energy distribution

is strongly affected by interstellar reddening, and the 2200 Å feature is prominent. The spectrum of the hot component is featureless in the long-wavelength region but filled with strong absorption lines below 2000 Å. The strongest of these are the doublets of Si IV and C IV near 1400 and 1550 Å, respectively; their relative and absolute strengths indicate a spectral type of B0 or B1. This result should be considered preliminary for two reasons: we have not yet secured an adequate set of spectra of spectral-type standard stars; and the contributions of interstellar lines to the observed absorptions cannot be determined at the resolution employed.

o Cet (Mira)

Mira is a close visual binary whose companion was first discovered spectroscopically (Joy 1926). When the red variable is near minimum light, the companion dominates the spectrum below 4000 Å. Its near-ultraviolet spectrum, however, is not classifiable, as it shows only broad hydrogen lines with P Cygni profiles. The companion is sometimes called an O star, sometimes a B star; in any case its faintness compared to the M giant primary indicates that it lies below the main sequence. The companion undergoes both slow and rapid variations (see Yamashita et al. 1978) and has been named VZ Cet.

Normal (i.e. single) Mira variables show a wide variety of emission lines in the optical region and hence might be expected to contribute some features in the ultraviolet. However, our IUE exposures on R Leo, R LMi, and R Hya do not show any definite features except the Mg II doublet at 2800 Å. We were expecting, therefore, that the ultraviolet spectrum of Mira itself would be essentially that of the companion. This is indeed the case in the long-wavelength region, where the spectrum is continuous with superimposed Mg II emission. The short-wavelength spectrum, however, is not that of a star but that of a nebula.

The spectrum of Mira from 1200 to 1950 Å is shown in Figure 1. Many strong emission lines are present, while the continuum from the hot star is relatively weak and surprisingly red. This 60-min exposure was made on January 28, 1980 when the primary was a bit past maximum light (the Fine Error Sensor registered a visual magnitude of 4.4). Since the long-wavelength region was well exposed in only 5 min, one might have expected the continuum of the hot star to be greatly overexposed in one hour in the short-wavelength region. Either the companion is not as hot as usually thought, or it is strongly reddened by circumstellar or interstellar material.

Most of the emission lines in Figure 1 are readily identifiable with the strongest transitions of abundant ions. What is remarkable is the wide range of excitation present. All the lines normally seen in high-excitation nebulae (N V, Si IV, C IV, He II, etc.) are there, but in addition there are strong lines of O I, C I, and Si II, which characterize the low-excitation chromospheres of K and M giants. Clearly there exists a wide range of temperature in the gas producing the emission. We note also that the semi-forbidden lines of O III], C III], Si III], and probably N III] are quite strong, indicating that at least some of the emitting gas is at low density.

Since it is likely that the primary star is losing mass with each annual cycle of its light variation and that this material fills a large volume of space around both stars, it is easy to see how a wide range of temperature and density could arise. Nearly all of the circumstellar gas can be illuminated by the hot star, and this radiation is most intense near the hot star while the density is probably highest in the immediate vicinity of the cool primary star.

Models of the Mira system will have to account for the relatively red color of the hot companion and its faintness in the short-wavelength region. It does not seem likely that it is as cool as it looks if it can excite the nebula so effectively. The great strength of the emission lines would tend to argue against interstellar absorption, or absorption from a dust shell surrounding the entire system, as the mechanism responsible for suppressing the spectrum of the hot star. At the same time, absorption occurring closer to the hot star would reduce its efficacy in exciting the emission spectrum, and in any case it is hard to understand how grains of any kind could exist near the hot star. A quantitative study of the relative emission line strengths might show whether or not they suffer selective absorption.

CH Cygni

This semiregular variable of type M7 III has gone through several episodes of "activity" — notably in 1963, 1967, and 1977 — during which the near-ultraviolet spectrum has become covered by a hot continuum, and emission lines of relatively low excitation (mainly Fe II) have appeared throughout the optical region. Both single-star and binary models have been proposed for CH Cyg. Recently, Yamashita and Maehara (1979) have detected changes in the photospheric radial velocity of the M star and have suggested that it is a binary system with a period of 5750 days (about 16 years) and a velocity semi-amplitude of 6.8 km/sec.

The spectrum obtained with IUE in the short-wavelength region leaves no doubt that a hot secondary star is present. Not only is the spectrum very bright (the optimum exposure time proved to be 5 min for low-resolution SWP images) but also the spectrum contains absorption lines of C IV, Si IV, etc. which presumably arise in the photosphere of the hot star. A spectral classification should be possible when more standards have been collected. The most conspicuous feature in the short-wavelength region, however, is one that does not belong in the spectrum of a hot star at all — a very strong emission line of O I! Since this line at 1300 Å can be pumped by Ly β photons (Bowen 1947), it seems that CH Cyg must represent an unusually favorable case for the operation of this fluorescence mechanism, with the hot star supplying the Ly β photons and the cool star supplying the neutral gas. On the other hand, the absence of detectable Ly α emission may make it hard to maintain that an adequate supply of Ly β photons is available.

In the long-wavelength region, after overexposing the spectrum in 2 min at low resolution, we took subsequent exposures at high resolution (optimum exposure time 40 min). Three plates were obtained, separated by intervals of several months; all show a large number of rather weak emission lines, but on

the most recent plate the Fe II emission is decidedly weaker than on the other two. Sections of two of these spectra are shown in Figure 2. The upper panel, which covers the interval from 2600 to 2650 Å, shows that the Fe II lines of multiplet (1) were much stronger in May 1979 than in January 1980. The lower panel covers the region from 2750 to 2800 Å on the same two dates and includes the 2795 Å line of Mg II. This line is broad and strong in emission and contains two distinct absorption components separated by 110 km/sec; the other member of the Mg II doublet at 2802 Å has a similar profile. Since the systemic velocity of CH Cyg is -58 km/sec (Yamashita and Maehara 1979), the longward absorption component has nearly zero velocity and is probably interstellar, while the shortward component is produced in a circumstellar shell that is expanding outward at about 50 km/sec with respect to the star. A similar expansion velocity was observed at the K line of Ca II by Yamashita and Maehara. On the other hand, the H α profile, recently studied by Anderson, Oliverson and Nordsieck (1980), is very different, with only a single absorption component dividing the emission into nearly equal parts. In that case no interstellar line is involved, and the absorption feature is at approximately the center-of-mass velocity — perhaps, as suggested by Yamashita and Maehara, because the Balmer absorption is associated with the circumstellar shell of the hot star, which in recent years has been in front of the M giant and moving across the line of sight.

AR Monocerotis

This 21-day eclipsing binary has a spectral type of K0 II; no evidence of the secondary star is seen spectroscopically. The secondary must be a fairly large star because the primary eclipses are about 0.8 mag deep (Payne-Gaposchkin 1944). The strange thing about this system is that the primary eclipse occurs when, according to the radial-velocity curve, the K star is in front (Sahade and Cesco 1944).

To check the possibility that the companion might be of relatively early type, AR Mon was observed at low resolution with exposures of 30 and 90 min in the long- and short-wavelength regions. The spectrum seems normal for an early K giant, with chromospheric emission lines of Mg II and O I and transition-region lines of C II, C IV, and N V. A weak continuum was recorded down to about 1700 Å, and its color is approximately normal for a K star. We conclude that the companion is no hotter than type G and probably is cooler than the primary.

BL Telescopii

This 778-day eclipsing system has many peculiarities. Although the primary has been classified as an F8 supergiant (Cousins and Feast 1954), the system has a large radial velocity, high galactic latitude, and appreciable proper motion. The primary eclipses are 2.0 mag deep, and the spectroscopic orbit (Wing 1963) indicates that the secondary must be at least as massive as 2 M $_{\odot}$.

At minimum light, weak TiO features have sometimes been recorded in the

red, and this suggests that the companion is an M star (Cousins and Feast 1954). On the other hand, Feast (1966) has offered the suggestion that the TiO features are produced near the limb of the F supergiant and that the eclipses are caused by a dense H II region ionized by, and surrounding, a hot subdwarf secondary.

We have observed BL Tel both outside eclipse (1979 February 11) and in eclipse (1979 May 26). Readings taken with the Fine Error Sensor indicate that the eclipse was 1.3 mag deep visually at the time of our second observation, while the fluxes at representative wavelengths in the ultraviolet showed changes of 1.0 to 1.5 mag. The spectrum seen in the ultraviolet is that of an F star, with a strong absorption feature due to the Mg II doublet and weaker absorptions as far shortward as 1700 Å. No chromospheric emission was recorded, and no significant changes in the spectrum (other than its intensity) occurred as a result of the eclipse. It would appear that spectroscopic evidence of the companion should be sought not in the ultraviolet but in the infrared.

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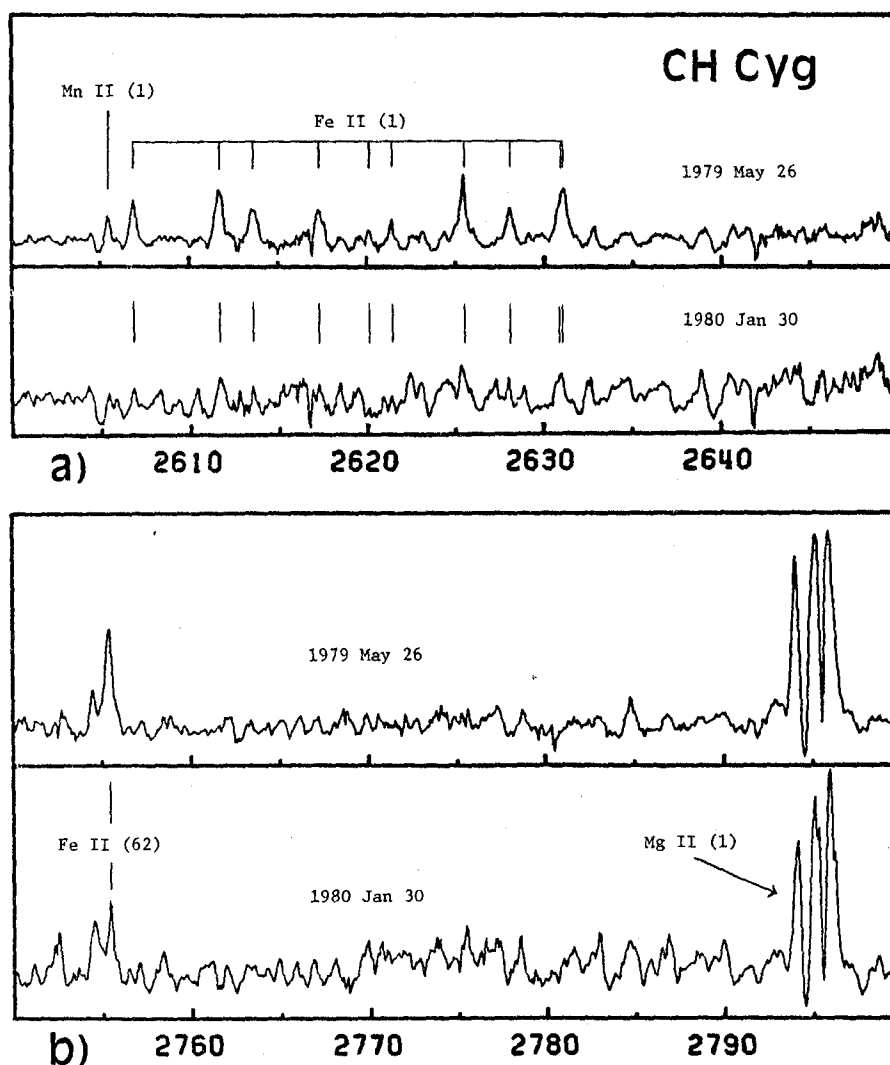


Figure 1.--The spectrum of Mira (o Ceti) in the short-wavelength region. The continuous spectrum from the hot companion is surprisingly faint and is probably obscured. The rich emission-line spectrum shows a wide range of excitation and probably arises in a large volume of gas which surrounds the entire system and is illuminated by the hot secondary. The Ly α line is largely geocoronal, but a stellar component comparable in strength to O I λ 1300 is also present. The feature near 1500 Å marked with an 'X' is spurious. In the long-wavelength region, the spectrum is dominated by the continuum of the hot star with superimposed Mg II emission.

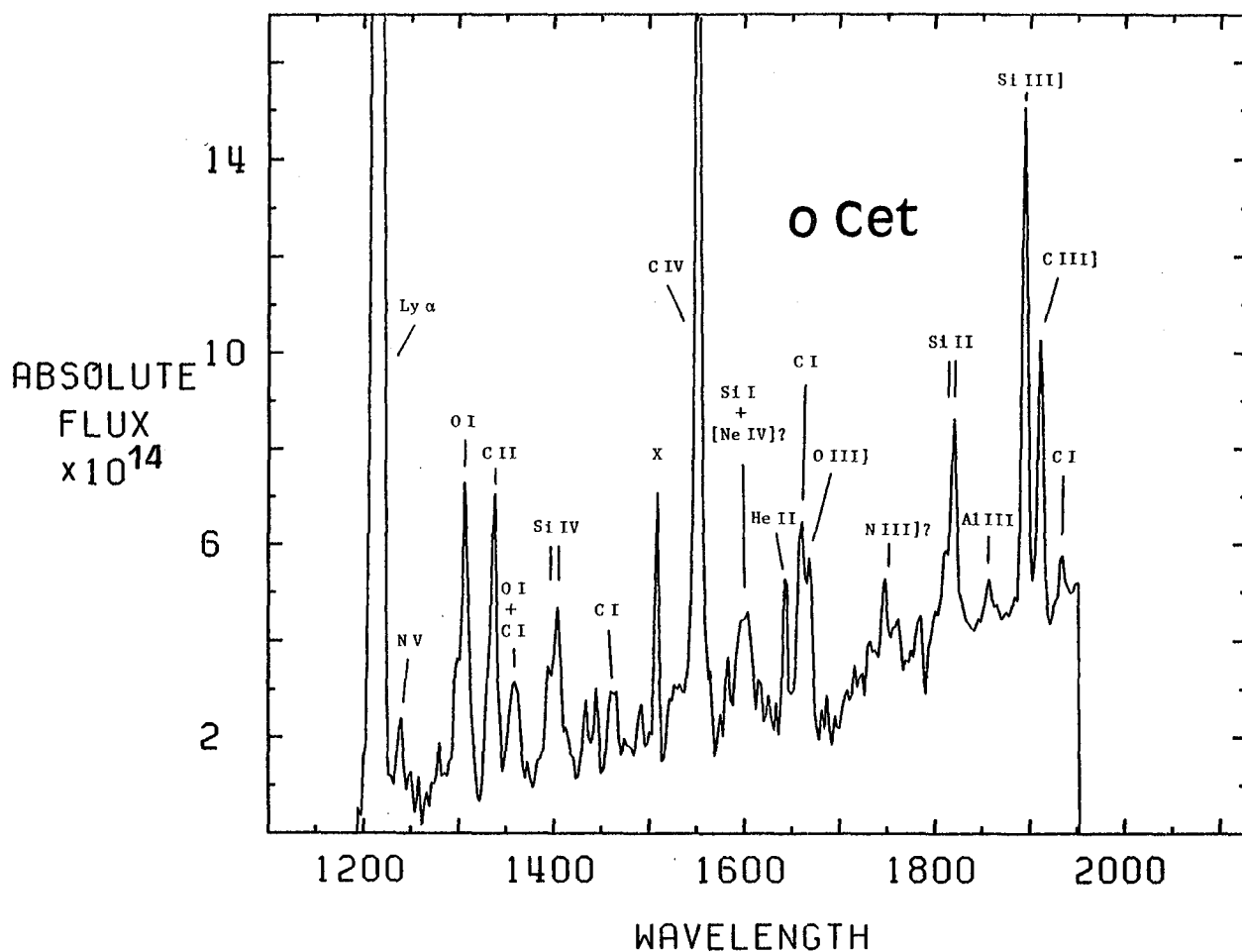


Figure 2.--Segments of high-resolution spectra of CH Cyg obtained on two different dates. (a) The region 2600-2650 Å, showing emission lines of Fe II and Mn II which were stronger on May 26, 1979 than on January 30, 1980. (b) The region 2750-2800 Å containing the 2795 Å line of Mg II, which shows both interstellar and circumstellar absorption components.